A Survey of Geoduck Populations in the Griffith Harbour Area, North Banks Island, in August 1995

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A SURVEY OF GEODUCK POPULATIONS IN THE GRIFFITH HARBOUR AREA, NORTH BANKS ISLAND, IN AUGUST 1995

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ABSTRACT

Hand, C.M. and G. Dovey. 2000. A survey of geoduck populations in the Griffith Harbour area, North Banks Island, in August 1995. Can. Manuscr. Rep. Fish. Aquat. Sci. 2541: 20 p.

A survey of the geoduck (*Panopea abrupta)* population in the Griffith Harbour area on northwest Banks Island, British Columbia, was conducted by the Underwater Harvesters Association and Fisheries and Oceans Canada in August, 1995. The purpose of the survey was to estimate the density of geoducks in the general area of reported beds and to verify the location of commercial beds. Survey densities are used to calculate quotas for the geoduck fishery.

A total of 48 systematically-placed transects were completed over 150 hectares of subtidal seabed in the Griffith Harbour area. Transects were post-stratified into four sites, each of which constituted a more or less continuous geoduck bed. Mean geoduck density was estimated to be $1.7/m^2$, $2.8/m^2$, $4.2/m^2$ and $0.2/m^2$ for Sites 1 to 4, respectively. Site 4 was excluded from calculations for overall density because it was a rocky reef and not suitable habitat for geoducks. Site 3 contained some extremely high geoduck densities, in the order of $30/m^2$. The mean density for Site 3 excluding these extreme data was $2.4/m^2$. Sites 1, 2 and 3 were combined to estimate overall density for use in quota calculations. The mean overall density of geoducks in Griffith Harbour beds was $2.9/m^2$ with a 95% confidence interval of $1.9/m^2 - 4.1/m^2$. With extreme data from Site 3 excluded, the estimate was $2.2/m^2$ (95% CI 1.6-3.0/m^2). These density estimates were 61% and 22% greater than the previous estimate of $1.8/m^2$ used to calculate quotas prior to this survey. Use of the lower density estimate is recommended for this area, and especially if survey densities are to be extrapolated to other, unsurveyed geoduck beds.

RÉSUMÉ

Hand, C.M. and G. Dovey. 2000. A survey of geoduck populations in the Griffith Harbour area, North Banks Island, in August 1995. Can. Manuscr. Rep. Fish. Aquat. Sci. 2541: 20 p.

Un recensement de la population de panopes (*Panopea abrupta)* du secteur de Griffith Harbour, au nord-ouest de l'île Banks, en Colombie-Britannique, a été effectué par l'Underwater Harvesters Association et Pêches et Océans Canada, en acût 1995. L'objet de ce recensement était d'évaluer la densité de la population de panopes dans le secteur réputé abriter des bancs de panopes et de vérifier l'emplacement des bancs susceptibles d'être exploités commercialement. La densité est l'un des critères d'établissement des quotas de pêche à la panope.

Un total de 48 sections systématiques ont été établies sur une superficie de 150 hectares de fond infratidal, dans la zone de Griffith Harbour. Les sections ont été subdivisées en quatre sites, dont chacun correspondait plus ou moins à un banc de panopes continu. La densité moyenne des populations de panopes a été estimée à 1,7/m^2 , 2,8/m^2, 4,2/m^2 et 0,2/m^2 pour les sites 1 à 4 respectivement. Le site 4 a été exclu du calcul de la densité globale parce qu'il s'agissait d'un récif rocheux non adapté à l'établissement de panopes. Le site 3 contenait des zones où la densité de panopes était extrêmement forte (de l'ordre de 30/ m^2). La densité moyenne établie pour le site 3, hormis les zones de densité extrême, était de 2,4/m^2. Les sites 1, 2 et 3 ont été combinés pour établir la densité totale aux fins du calcul des quotas. La densité totale moyenne de panopes dans les bancs de Griffith Harbour était de 2,9/m^2, avec un intervalle de confiance de 95 % compris entre 1,9/m^2 et 4,1/m^2. Si l'on exclut les densité extrêmes trouvées dans le site 3, la densité a été établie à 2,2/m^2 (IC 95% 1,6-3,0/m^2). Ces chiffres étaient supérieurs de 61% et de 22% respectivement aux chiffres précédents de 1,8/m^2 et qui ont servi à établir les quotas antérieurs à ce recensement. L'utilisation du chiffre de densité le plus bas est recommandée pour ce secteur, en particulier si les chiffres sont extrapolés à des bancs de panopes n'ayant pas fait l'objet de recensements.

1.0 INTRODUCTION

Geoduck clams (*Panopea abrupta* (Conrad, 1849)) have been harvested commercially in British Columbia (BC) since 1976. Fishermen target concentrations of clams found in beds of soft substrate and, to date, an estimated 1,200 hectares of geoduck beds have been documented throughout the BC coast. The $29.6 million fishery (1998), among the highest valued in BC, is managed with individual vessel quotas and a three-year rotational system. The fishery and biology are summarized by Hand *et al.* (1998b).

Quotas for the fishery are determined from estimates of virgin biomass and an annual harvest rate of 1% (Hand *et al.* 1998b). Transect surveys provide the density information needed to calculate biomass, as well as a verification of the area of the beds. Initial estimates of geoduck density were based on large-scale surveys in Washington State (Goodwin 1978) and BC (Table 8 in Harbo *et al.* 1992), small-scale field studies (Breen and Shields 1983, Harbo and Adkins unpublished data, summarized in Table 13 in Harbo *et al.* 1992) and consultations with fishermen. Density estimates vary with geographical region and, for the North Coast region (Pacific Fisheries Management Areas 3, 4 and 5), they initially ranged from 1.0 geoduck/m^2 to 5.0/m^2. Following preliminary surveys of known beds in the North Coast in 1991 (Farlinger and Thomas 1991), the density estimate was reduced from 5.0/m^2 to 3.5/m^2 for the calculation of the 1993 quotas. The quotas for the 1996 North Coast fishery (the third rotational cycle) were calculated using a further reduced density estimate of 1.8/m^2, based on survey results from the Queen Charlotte Islands (Hand *et al.* 1998c) and corroborated by preliminary results from two surveys conducted on the Central Coast, Area 7. Quotas for 1999 in the Griffith Harbour area were based on density estimates of 2.2/m^2, from this survey (Hand *et al.* 1998b).

Fisheries and Oceans Canada (DFO), the geoduck Underwater Harvesters Association (UHA) and First Nations groups have collaborated on geoduck surveys since 1994 and, between 1994 and 1999, 33 surveys have been completed throughout the BC coast. This paper reports the results of a survey conducted on northwest Banks Island in the Griffith Harbour area in August 1995. Prior to this survey, there were no density data from the North Coast Region. Field activities were conducted by UHA divers and two contract biologists, one of whom was hired to function as the third-party, unbiased participant. The objectives of this survey were to (1) obtain density estimates for geoduck clams and horse clams (*Tresus spp.)* in known beds in the area, (2) verify the existence and extent of these beds, and (3) estimate the current biomass of geoducks in the survey area.

1.1 DESCRIPTION OF STUDY AREA

The Griffith Harbour area (Fig. 1) is a favoured fishing location that has been harvested since 1984. At the time of this survey in 1995, approximately 15% of all landings from the North Coast Region had been harvested from these beds. The area includes a wide mixture of substrate types, with pockets of soft substrate interspersed amongst islands and reefs. The series of beds share a common bedcode in the DFO database and, as a consequence, reported landings can only

be tracked to this general area rather than to the specific site of harvest. Prior to the survey in 1995, the total area of the surveyed beds was estimated to be 182.4 ha, from digitized chart polygons provided by fishermen.

For the fisheries up to and including 1993, the entire area, from Larsen Island to Solander Point, was managed as one Geoduck Management Area (GMA) with a quota of 180 t. This GMA was split into three areas of equal size for the next rotation in 1996, and a reduced quota of 128 t was partitioned equally amoung the three areas. The area subdivisions were maintained for the 1999 fishery, and quotas of 22.7 t, 52.2 t and 52.2 t were set for north, central and south sections, respectively, on the advice of fishermen.

2.0 METHODS

2.1 FIELD METHODS

2.1.1 Dive Survey Design

The location of known geoduck beds, as reported by fishermen in their harvest logs, was used in the design phase of the survey to establish the general area of survey coverage. Transect locations were assigned by DFO personnel onto charts *a priori*, in order to reduce possible bias under field conditions. Survey protocols follow the Survey Type 1 methodology outlined in Campbell *et al.* (1998a). This is a two-stage design where transect locations were systematically determined at the first stage and a complete census of secondary sampling units, or quadrats, was taken at the second stage. The first transect location was randomly selected at the northern limit of the survey area and, thereafter, spaced approximately 300 m. apart at the 3.0 m (10 ft) chart datum depth (Fig. 1).

In the field, the location of the first transect line was determined using geographical references on the shoreline, Global Positioning System (GPS) readings and depth sounder readings. Thereafter, transect location was determined by measuring the predetermined distance between each transect with a loggers hip chain. The lead-core transects were laid perpendicular to depth contours and extended from 3 to 18 m (10 to 60 feet) diving depth. Transects were terminated at submerged reefs of less than 3 m depth or valleys deeper than 18 m and continued on the other side with a new transect number. Final start and end positions of the transects were recorded with GPS, accurate to within 30 m. Exposure to weather and tidal currents was recorded for each transect using DFO exposure codes.

The lead-core transect lines were marked every 5 m with a cable tie to define the end of each secondary sampling unit. Two SCUBA divers worked together, one on either side of the transect, and counted visible geoduck shows or dimples[1] within 1 m (using a metre stick) of each side of the transect. At each cable tie marker, the divers stopped to record the number of geoducks, along with the number of horse clams, the depth, substrate type, algal cover and the

[1] Shows are visible siphons. Dimples are visible indentations in the substrate left by a retracted siphon. Dimples were counted as shows if the siphon retracted in response to probing.

neck exposure (the percentage geoduck necks extending greater than 1-2 cm above the substrate surface). The data from either side of each 5–metre section were pooled and, thus, one data record is the number of geoducks, the number of horse clams and the auxiliary data for each $10m^2$ quadrat.

Calibration dives on one 20 m test-transect were conducted to compare and quantify the detection abilities of the survey divers. This is done because geoduck shows can be subtle, and detection skills of divers can therefore have an impact on survey results. Each diver swam this calibration line with each of the other divers at least once.

2.1.2 Show Factor Plots

Individual geoduck siphons are sometimes withdrawn below the surface of the substrate due to physical and/or biological effects (Goodwin 1977, Turner and Cox 1981) and are not readily visible to divers. The fraction of geoduck siphons that are readily visible to divers is the show factor.

The show factor was estimated by monitoring the same 10 x 2 m plots every day through the duration of the survey. Each day, the number of shows was recorded and flags were placed beside geoducks showing for the first time. The show factor for any given day is determined by dividing the number of shows by the total number of geoducks flagged during the survey.

The location of the show factor plots (Fig. 1) were chosen to be representative of the substrate, depth and exposure encountered during the survey. The other criterion was that the show factor plots be placed in areas of relatively high geoduck abundance so that show factors were estimated from a larger sample of animals.

2.2.1 ANALYTICAL METHODS

2.2.1 Depth Correction

Observed depths were converted to tide height below chart datum using tidal prediction from the harmonic station at Prince Rupert, corrected with the deviation from the secondary port in Griffith Harbour.

2.2.2 Post-stratification and data exclusion

The survey was not stratified by habitat, but rather, transects were systematically placed within the general area of harvest. This sometimes resulted in observations being recorded from substrates not suitable for geoducks. Since, for stock assessment purposes, the results of this survey will be extrapolated to unsurveyed geoduck beds, an attempt was made to create a data set that would measure the density of geoducks in only the commercial beds. We used the detailed reports of the north coast on-grounds fishery observer as independent information to determine the location of commercial harvest. Transects that were clearly outside of harvest areas were excluded from the data set for the calculation of overall density. The remaining transects were

logically grouped into survey sites, constituting more or less continuous geoduck beds, for further analysis (Fig. 1).

2.2.3 Show Factor Proportions

The proportion of geoducks showing on day *i* (SP_i) in any given area was calculated as

$$SP_i = \frac{X_i}{\sum_i T_i} \quad (1)$$

where X_i is the number of geoduck shows in the plot in day *i* and T_i is the number of previously unobserved shows on day *i*, the sum of which is the total number of enumerated geoducks in the plot.

The results of the show factor observations were applied to the data by using the results from the same day's observations from the nearest plot. If a transect was completed over two days, the show factors were averaged over the two days.

2.2.4 Area Estimation

Two methods were used to estimate the area of geoduck beds surveyed. Initial estimates of commercial bed area were obtained from digitized polygons drawn on DFO reference charts. These polygons are based on geo-referenced fishing information provided by fishers on harvest logs, as a condition of licence. As part of the on-going process of updating and improving the geoduck spatial database with the latest information, the polygons representing the surveyed beds were redrawn using survey results, plus any new harvest log or on-grounds observer information.

The area-surveyed (the sum of the area of all possible transects) and was calculated as the product of the mean transect length in each site and the linear distance along the shore, as measured from the appropriate nautical chart. This was the area within which transects were systematically placed, and the estimate was used to calculate population biomass for the Griffith Harbour geoduck beds.

2.2.5 Survey Density, Population Number and Biomass Calculations

Analytical procedures follow Campbell *et al.* 1998a. Geoduck counts for each transect (g_j) were adjusted for the proportion of geoducks not showing by:

$$g_j = \frac{b_j}{SP_i} \quad (2)$$

where, for each transect *j*, b_j is the total raw count of geoducks and SP_i is the mean proportion of geoducks showing on the day that the data were collected. Parametric estimates of mean density

for each study site or bed k (d_k) were calculated as the ratio of sums for the adjusted geoduck counts and the transect area as:

$$d_k = \frac{\sum_j g_j}{\sum_j a_j} \tag{3}$$

where a_j is the area of transect j in square metres. This ratio estimator of mean density assumes a straight-line relationship between the estimation variable (number of geoducks) and the auxiliary variable (transect area) (Fig. 2). Area can be viewed as an auxiliary variable, which enables the calculation of the population mean when the total survey area can only be approximated. Use of the ratio estimator also reduces the variance of the estimate of mean density due to unequal transect lengths, since the transect counts are weighted appropriately. The variability seen in Figure 2 results from the pooling of all data over substrate types, some of which are less suitable as geoduck habitat. There is, however, a positive relationship between transect area and the number of geoducks counted.

Because the distribution of the density data is skewed (Fig. 3), non-parametric confidence intervals for the mean geoduck density were calculated using bootstrap techniques (Efron and Tibshirani 1993). This procedure is referred to as the "naive" bootstrap because the method is generally expected to be biased when applied to complex survey designs, particularly in the case of ratio estimators (Rao and Wu 1988). The procedure randomly samples n transects with replacement from the n sampled transects.

Each time a transect was sampled for the bootstrap, a show-factor was also sampled to correct the geoduck count. The corrected geoduck count for selected transect j (g^*_j) is calculated by:

$$g^*_j = \frac{b^*_j}{h^*_j} \tag{4}$$

where

$$h^*_i = \frac{Binom(N_{show}, h_{day})}{N_{show}} \tag{5}$$

Binom(N,h) is a random variate with a binomial distribution. N_{show} is the total number of geoducks observed in the show-factor plot, h_{day} is the show-factor for the day the transect was surveyed, and b^*_j is the estimated number of geoducks observed in the transect.

The n g^*_j's are added, as are the corresponding areas for the resampled transects, and the mean density d_k^* calculated as in equation (3). The process was repeated 1000 times to obtain 1000 estimated mean densities: d^*_1, d^*_2, ...d^*_{1000}. Bootstrap 95% confidence intervals were then constructed using the percentile method. The 1000 bootstrap estimates of the mean were sorted

and the $1000(0.025)^{th}$ value and $1000(1\text{-}0.025)^{th}$ value were used as the bounds of the 95% confidence interval.

For each of the 1000 calculated g^*_j's, a corresponding population number (p_j) and biomass (b_j) are calculated as

$$p_j = g_j(l + se(l)z) \tag{6}$$

and

$$b_j = p_j(w + se(w)z) \tag{7}$$

where l is the size of the bed in square metres, $se(l)$ is the estimated standard error of the size of the bed, w is the estimated mean weight of a geoduck in kilograms, $se(w)$ is the estimated standard error of the weight of a geoduck and z is a random number from a standard normal population. Estimates of mean weight were obtained from market samples, which are considered un-biased because the harvest of geoducks is not size-selective. The mean population number and biomass for each site are calculated by summing the p_j's and b_j's and dividing by 1000. The confidence intervals for the population and the biomass are calculated as for density, with the percentile method.

3.0 RESULTS

A total of 44 transects were completed by the dive teams. An additional four transects were sounded only and determined to be on bedrock substrate; these were included in the dataset as zero counts. Transects varied in length between 35 m and 470 m over extremely varied substrate combinations of sand/shell/mud, bedrock, boulders and gravel. The exposure of the site to winds, waves and current ranged from moderate to high. In the post-stratification, transects 8 and 37 and all transects within Site 4 were excluded from the data set for density calculation (Fig. 1).

3.1 FISHERY REMOVALS

A total of 839 t of geoducks were reported to have been harvested from the areas surveyed prior to 1995 (Table 1). A estimated mean weight of 1.242 kg, from fishery market samples (Burger *et al.* 1998), was used to convert biomass landed to numbers of geoducks. Reported landings were corrected with a factor that accounts for the difference in landings between sales slips and harvest logs, on a Pacific Fishery Management Area (PFMA) basis. Annual corrected landings have varied between 35 t and 300 t, and an estimated total of 1,268 t have been landed from the Griffith Harbour area to date. The decrease in density of geoducks due to removals by the commercial fleet prior to this survey was calculated as the ratio of number landed (uncorrected) to the digitized area of 182.4 ha. The overall decrease in density of geoducks from fishery removals is estimated to be at least $0.37/m^2$.

3.2 SHOW FACTORS

Three show factor plots were monitored over a period of 9 days (Table 2). The first day of observations were not considered due to the disruptive effect on the geoducks of installing the plot. The proportion of geoducks showing was high, ranging from 94.8 % to 100 %, which is expected during summer months when storm activity is minimal (Goodwin 1977). The show factors used in the density estimates affect the estimated biomass by only a few per cent.

3.3 DIVER CALIBRATION

All survey divers counted geoducks on both sides of the calibration line at least once during the survey. It became apparent, however, that these data could contain variability due to sources other than the detection skills of divers. For example, the physical disturbance caused by the divers in swimming the line would affect same-day comparisons, and differing oceanographic conditions may affect comparisons when tested on different days. There may also be variation due to the transect line itself moving. These effects could overwhelm any difference that may have resulted from observation skill of the divers, and therefore the calibration data was not considered to be a reliable method of indexing divers' counts. Any potential under-counting due to lack of skill was therefore not corrected for, but this is felt to be unlikely because all of the divers participating in the survey were experienced commercial fishermen or geoduck research divers.

3.4 AUXILIARY DATA

The effects of depth and substrate type on density were tested from individual records using Kruskal-Wallis tests. Geoduck density increased with depth ($p<0.05$) and, not surprisingly, all density measures were higher on soft substrates than on mixed or hard substrates ($p<0.05$) (Fig. 4). This observation is consistent with the results of many other geoduck surveys (e.g. Campbell *et al.* 1995a, 1995b; Campbell *et al.* 1998b).

3.5 GEODUCK BED AREA

The digitized area of chart polygons that represent the surveyed geoduck beds (derived from harvest log data) was measured at 182.4 hectares prior to the survey. This estimate was revised to 152.5 ha when the survey information and recent fishery activities were taken into account. All beds that had been drawn around McCoy Rocks (Fig. 1) were deleted, since the survey results indicated that the substrate is primarily bedrock and reports from the on-grounds observer verified that no fishing had ever occurred there. The area at the north end of the survey, covered by transects 1 and 2, was also deleted because exploration by fishermen, as reported by the observer, indicated that this portion of the harbour had a substrate described as 'crunchy mud' from which it is difficult to extract geoducks. It is unlikely that this area would be harvested, given that superior areas exist nearby. The new estimate of digitized bed area was incorporated into the spatial database of geoduck beds, used for calculating quota estimates.

The estimate of area-surveyed (sum of the area of all possible transects) of 149.7 ha is in close agreement to the revised digitized area estimate of 152.5 ha.

3.6 DENSITY AND BIOMASS ESTIMATES

Transect densities (not corrected for show factor) ranged from 0 geoducks/m^2 to 11 geoducks/m^2 (Table 3). Although the original survey design was not stratified by bed, four distinct geographic areas were evident from the data and from independent information on the location of observed fishing activities. Transects were grouped into these sites for further analysis. Transects 1 to 7 in Griffith Harbour and 9, 10, 31-35, 38-43 around Rawlinson Anchorage were combined into survey Sites 1 and 2, respectively. A rocky reef separates these two sites. Transects 16-18, 22-30, 35.1, 36 and 36.1 around Webb Is. and transects 12 to 15, 19, 20 and 21 around McCoy Rocks were combined into survey Sites 3 and 4, respectively.

The distribution of the number of geoducks per $10m^2$ quadrat, by site, are shown in Figure 5. The highest concentration of geoducks were found in Sites 2 and 3, with some 10 m^2 quadrats containing in excess of 300 clams. During the analysis, it was questioned whether these dense concentrations may have been false geoducks *Panomya spp* or *Mya truncata* (Harbo 1997), because survey divers reported that some of the shows in these areas were small. The observations have since been verified as geoducks by commercial fishermen in 1999 (Doug Stewart, north coast on-grounds observer, personal communication). Nonetheless, the transects containing these high-density segments (transects 28, 30 and 35.1) were excluded from a second data-set, and the results are presented separately. This was done to provide a more conservative estimate of geoduck density for the purpose of extrapolation to unsurveyed geoduck beds, since such concentrations of geoducks are highly unusual.

Mean density estimates with 95% confidence intervals for each survey site are shown in Table 4. Site 3 had, by far, the highest overall density at 4.2 geoducks/m^2. Results of analysis with transects 28, 30 and 35.1 excluded was a mean density of 2.4/m^2. Only one transect in Site 4 had appreciable densities, transect 19 (Table 3), while the rest of the area around McCoy Rocks was primarily rocky reef habitat. Although a bed was indicated on DFO reference charts in the vicinity of Site 4, the on-grounds observer records do not indicate that any harvesting activity has occurred in the area, except around transect 19. Site 4 was therefore not included in the analysis for overall density for the Griffith Harbour area.

The mean overall density in the Griffith Harbour area was 2.9 geoducks/m^2 for the whole dataset and 2.2/m^2 with extreme data from Site 3 excluded. Confidence limits were within approximately 38% of the mean for the whole data set and 32% for the filtered data set (Table 4).

Estimates of the population biomass ranged from 43 t in Site 4 to 3,072 t (1,767 t with filtered dataset) in Site 3, with the total estimated biomass for Sites 1, 2 and 3 of 5,361 t (4,129 t) (Table 4). This is comparable to the previous estimate of biomass of 4,104 t (Table 5), on which the 1996 quota was based (Hand *et al.* 1998a).

4.0 DISCUSSION

The density estimates of 2.9 geoducks/m^2 and 2.2/m^2 obtained from this survey are both higher than the previous estimate of 1.8 geoducks/m^2 that had been used to calculate the 1996 geoduck quotas. Despite the decrease in estimated bed area, estimates of biomass increased by 2% or 35%, depending on the estimate of density used. The precision of the means are fairly low, with 95% confidence limits plus or minus 41% and 34 %, respectively. When the transects with very high densities are excluded, the precision of the mean improved, to plus or minus 36% and 27%. Geoduck density estimates from other surveys conducted in the North Coast Region are comparable to the results obtained in Griffith Harbour. A survey in Principe Channel, around the northern tip of Banks Island, produced a density estimate of 2.16 geoducks/m^2, with 95% confidence bounds of $\propto \notin \subset$ 25% (Hand *et al.* in prep).

The estimated reduction in density of geoducks as a result of commercial fishing prior to the survey was revised from our initial estimate of 0.37/m^2 to 0.45/m^2, based on the reduced estimate for bed area of 149.7 ha. An estimate of the virgin density of geoducks can be provided by the sum of the survey density and the density removed, if one assumes that natural mortality and recruitment are equal. Since the effect of fishing on geoduck population dynamics is poorly understood, this assumption, which is reasonable in an equilibrium situation, may be invalid. The estimated virgin density may be overestimated if recruitment levels were higher than deaths due to natural causes. Such would be the case if there is a compensatory effect on recruitment or natural mortality. Nothing in the literature suggests that such is true for geoducks, and there is some indication that commercial geoduck harvesting may have an adverse effect on recruitment (Goodwin and Shaul 1984). No biological samples were collected during this survey, and so the proportion of the population recruited since the fishery began is unknown. A sample collected from Principe Channel in 1997, however, does not show strong modes in the 7 to 13 age range. It is therefore considered unlikely that estimates of virgin density, calculated as described above, would be over-estimated.

The high densities of clams found in Site 3 (up to 33.7/m^2) were later verified to be geoducks, however such densities are extremely rare. Data from three transects only (representing 8% of all transects) was responsible for a 32% difference in density, from 2.2/m^2 to 2.9/m^2. Unless the geoduck beds can be partitioned in such a way that would ensure that harvest levels are proportionate to density on a fine spatial scale, it would seem prudent to ignore these outliers and calculate biomass and quota estimates from the more conservative of the density estimates. Use of the lower density estimate is especially recommended when survey results are extrapolated to unsurveyed geoduck beds in the north coast. The extrapolation of these survey densities to un-surveyed geoduck beds in the north coast will have an positive effect on biomass estimates and quotas. The previous estimate of geoduck density used to calculated quotas (1.8/m^2) was an extrapolation from surveys conducted on the Queen Charlotte Islands, the only north coast available at the time. Results from this survey, along with five others in preparation, provide information more specific to North Coast Region geoduck beds.

Commercial quotas for the Griffith Harbour area have not been greatly affected by the results of this survey. Through a combination of adjustments to the density and to bed area, and

quota reductions to offset estimated levels of previous over-harvesting, three-year quotas have remained around 125 t since 1996. The most recent annual-equivalent harvest level of 42.3 t equates to an exploitation rate of 1%, which is in line with the current management objective.

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Table 1. Reported and adjusted landings (kg and number of animals) of geoducks from the Griffith Harbour area, 1984 to 1999. Reported landings are adjusted by the ratio of reported landings from logbooks to sales slip landings (1984-1988) or validated landings (1989-1996), for Statistical Area 5. A mean weight of 1.241 kg, obtained from market samples, was used to convert weight landed to number landed.

	Year	Landings			
		Reported on Logbooks		Adjusted for under-reporting	
		(kg)	(#)	(kg)	(#)
Prior to survey	1984	70,919	57,103	99,286	79,944
	1985	144,270	116,164	201,978	162,630
	1986	29,464	23,724	41,250	33,214
	1987	116,524	93,824	163,134	131,353
	1988	25,000	20,129	34,999	28,181
	1990	287,648	231,610	299,154	240,874
	1993	165,163	132,987	171,769	138,306
	Subtotal	838,987	675,541	1,011,570	814,502
Post survey	1996	129,344	104,146	129,344	104,146
	1999	127,000	102,342	127,000	102,342
Total to Present		1,095,330	882,029	1,267,914	1,020,990

Table 2. Summary of the percent of geoducks showing and the number of flagged geoducks (n) in show factor plots for the survey at Griffith Harbour Aug. 15-23, 1995. Plots were left undisturbed on the 16th after installation on the 15th.

DATE	SHOW FACTOR PLOT						daily mean	standard deviation
	# 1		# 2		# 3			
	%	n	%	n	%	n	%	
Aug. 15	89.3	25	85.4	164	79.7	55	84.8	4.8
Aug. 16								
Aug. 17	96.4	28	94.8	182			95.6	1.2
Aug. 18	100.0	28	95.8	187	97.1	67	97.6	2.1
Aug. 19			97.4	187	95.7	67	96.5	1.2
Aug. 20	96.4	28			95.7	67	96.0	0.6
Aug. 21			97.9	188	100.0	69	99.0	1.5
Aug. 22	96.4	28	97.9	189	100.0	69	98.1	1.5
Aug. 23	96.4	28	99.5	192	100.0	69	98.6	1.9
Average/Total[1]	97.1	28	97.2	192	98.1	69		

[1] Does not include observations for Aug. 15.

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Table 3. Summary of transect statistics for the geoduck survey at Griffith Harbour, 1995, including depth range, transect length, show factor, observed geoduck number (not corrected by show factor), minimum and maximum counts per $10m^2$, density ($\#/m^2$), exposure of the transect location, water visibility, percent geoduck necks exposed and dominant substrate.

Survey Site	Trans.	Date	Time Start	Depth (m) Min	Depth (m) Max	Transect Length (m)	# of Quadrats	Show Factor	Geoducks Counted Total	Geoducks Counted Min	Geoducks Counted Max	Density ($\#/m^2$)	Site Exp.[1]	Water Visibility (m)	Neck Exp. (%)	Substrate[2]
1	1	16-Aug	1000	2.5	10.7	355	71	0.964	179	0	14	0.25	4	7.6	10	S/Sh/M
1	2	16-Aug	1212	2.7	12.6	470	94	0.964	418	0	44	0.44	4	6.1	10	S/M/Sh
1	3	16-Aug	1524	1.0	8.9	370	74	0.956	1182	0	50	1.60	4	6.1	20	S/M/Sh
1	4	17-Aug	0940	3.4	8.8	345	69	0.956	1260	0	85	1.83	4	6.1	20	S/Sh/Bo
1	5	17-Aug	1324	2.7	13.6	295	59	0.956	1856	0	108	3.15	4	6.1	35	S/M
1	5.1	17-Aug	1220	5.7	7.9	90	18	0.956	175	0	24	0.97	4	6.1	30	S/M/Bo
1	6	17-Aug	1701	4.5	11.3	380	76	0.956	1458	2	51	1.92	4	6.1	20	S
1	7	18-Aug	0856	1.1	11.2	330	66	0.958	2052	0	106	3.11	4	6.1	30	S/Sh/Bo
	8[3]	18-Aug	-			no transect laid							4	6.1		R
2	9	18-Aug	1144	5.2	12.9	220	44	0.958	325	0	16	0.74	4	6.1	30	S/M
2	10	18-Aug	1302	2.3	13.6	105	21	0.958	127	0	12	0.60	4	6.1	30	S/Bo
2	31	21-Aug	1128	3.9	12.6	160	32	1.000	547	0	64	1.71	4	4.6	20	M/S
2	32	21-Aug	1317	1.9	10.2	165	33	1.000	127	0	11	0.38	4	4.6	35	M/S
2	33	21-Aug	1429	2.6	14.8	200	40	1.000	2247	0	169	5.62	4	4.6	50	S/Sh/Bo
2	34	21-Aug	1537	6.6	15.3	55	11	1.000	957	0	152	8.70	4	4.6	40	S/Sh/Bo
2	35	21-Aug	1612	4.6	15.5	100	20	1.000	350	0	64	1.75	7	4.6	20	S/Bo
2	38	22-Aug	1021	5.6	13.8	105	21	1.000	444	0	75	2.11	7	4.6	20	S/Sh/G
2	39	22-Aug	1118	5.6	11.8	125	25	1.000	838	0	182	3.35	7	4.6	30	Sh/S/Bo
2	40	22-Aug	1222	3.8	12.9	45	9	1.000	483	0	151	5.37	7	4.6	20	S/Bo
2	41	22-Aug	1248	4.4	14.1	30	6	1.000	283	0	256	4.72	7	4.6	30	S/Bo/C
2	42	22-Aug	1312	5.5	13.3	45	9	1.000	10	0	4	0.11	7	4.6	0	Sh/Bo/C
2	42.1	22-Aug	1430	0.1	5.7	65	13	1.000	133	0	47	1.02	4	6.1	20	S
2	43	22-Aug	1337	6.4	12.6	65	13	1.000	1220	0	219	9.38	7	3.0	75	S/Sh
3	16	19-Aug	1021	7.9	12.7	360	72	0.957	536	0	28	0.74	7	6.1	20	Sh/Bo/G
3	17	19-Aug	1136	0.1	13.8	50	10	0.957	21	0	10	0.21	7	6.1	5	Bo/C/R
3	18	19-Aug	1202	2.8	15.7	100	20	0.957	3	0	3	0.02	4	6.1	0	Bo/Sh
3	22	19-Aug	1633	2.8	14.2	155	31	0.957	299	0	96	0.96	8	6.1	20	Bo/Sh/C

Table 3 (cont'd)

Survey Site	Trans.	Date	Time Start	Depth (m) Min	Depth (m) Max	Transect Length (m)	# of Quadrats	Show Factor	Geoducks Counted Total	Geoducks Counted Min	Geoducks Counted Max	Density (#/m^2)	Site Exp.[1]	Water Visibility (m)	Neck Exp. (%)	Substrate[2]
3	23	20-Aug	0920	2.5	12.7	90	18	0.957	118	0	40	0.66	7	4.6	0	Bo/S/Sh
3	24	20-Aug	0959	4.6	14.3	95	19	0.957	757	0	158	3.98	8	4.6	25	S/Bo
3	25	20-Aug	1055	10.0	13.3	200	40	0.957	764	0	59	1.91	8	4.6	15	Sh/S
3	26	20-Aug	1241	12.4	13.4	100	20	0.957	74	0	23	0.37	8	4.6	15	S/Sh
3	27	20-Aug	1323	2.9	14.8	185	37	0.957	2807	0	182	7.59	8	4.6	10	S/M/Bo
3	28	20-Aug	1447	3.2	16.2	275	55	0.957	4776	3	264	8.68	4	6.1	45	S/Sh
3	29	20-Aug	1730	3.8	13.4	195	39	0.957	1155	0	99	2.96	7	4.6	50	S/Sh/R
3	30	21-Aug	0920	6.0	14.4	240	48	1.000	5288	0	337	11.02	8	4.6	20	S/Sh/R
3	35.1	21-Aug	1650	5.3	14.7	155	31	1.000	1415	0	318	4.56	8	4.6	55	Sh/S
3	36	22-Aug	0916	12.4	15.6	140	28	1.000	1447	5	162	5.17	7	4.6	15	Sh/S
3	36.1	22-Aug	1508	5.9	14.1	40	8	1.000	0	0	0	0.00	8	6.1		Bo/C
	37[3]	21-Aug	-			no transect laid							7			R
4	11[3]	18-Aug	-			no transect laid										R
4	12[3]	18-Aug	1638	4.7	13.1	35	7	0.971	0	0	0	0.00	7	6.1		R/Sh
4	12.1[3]	19-Aug	0903			no transect laid										R.Bo
4	13[3]	18-Aug	1558	9.0	13.5	100	20	0.971	30	0	13	0.15	7	6.1	0	Sh
4	14[3]	18-Aug	1423	7.9	12.3	100	20	0.971	0	0	0	0.00	7	7.6		Bo/Sh
4	15[3]	19-Aug	0940	0	12.0	60	12	0.957	0	0	0	0.00	7	6.1		Bo/Sh
4	19[3]	19-Aug	1320	4.7	15.6	90	18	0.957	225	0	74	1.25	8	6.1	20	Bo/C/Sh
4	20[3]	19-Aug	1413	3.9	13.6	285	57	0.957	12	0	3	0.02	8	4.6	5	Sh/Bo/C
4	21[3]	19-Aug	1540	6.8	15.1	100	20	0.957	1	0	1	0.01	8	6.1	0	Sh/Bo/R

[1] 4= Moderate exposure, 7=Ground swell normal, 8=High exposure.

[2] S=sand, Sh=shell, M=mud, Bo=boulder, R=bedrock, C=cobble, G=gravel.

[3] Transects that were excluded from data set for calculating density.

Table 3. Summary of transect statistics for the geoduck survey at Griffith Harbour, 1995, including depth range, transect length, show factor, observed geoduck number (not corrected by show factor), minimum and maximum counts per $10m^2$, density ($\#/m^2$), exposure of the transect location, water visibility, percent geoduck necks exposed and dominant substrate.

Survey Site	Trans.	Date	Time Start	Depth (m)		Transect Length (m)	# of Quadrats	Show Factor	Geoducks Counted			Density ($\#/m^2$)	Site Exp.[1]	Water Visibility (m)	Neck Exp. (%)	Substrate[2]
				Min	Max				Total	Min	Max					
1	1	16-Aug	1000	2.5	10.7	355	71	0.964	179	0	14	0.25	4	7.6	10	S/Sh/M
1	2	16-Aug	1212	2.7	12.6	470	94	0.964	418	0	44	0.44	4	6.1	10	S/M/Sh
1	3	16-Aug	1524	1.0	8.9	370	74	0.956	1182	0	50	1.60	4	6.1	20	S/M/Sh
1	4	17-Aug	0940	3.4	8.8	345	69	0.956	1260	0	85	1.83	4	6.1	20	S/Sh/Bo
1	5	17-Aug	1324	2.7	13.6	295	59	0.956	1856	0	108	3.15	4	6.1	35	S/M
1	5.1	17-Aug	1220	5.7	7.9	90	18	0.956	175	0	24	0.97	4	6.1	30	S/M/Bo
1	6	17-Aug	1701	4.5	11.3	380	76	0.956	1458	2	51	1.92	4	6.1	20	S
1	7	18-Aug	0856	1.1	11.2	330	66	0.958	2052	0	106	3.11	4	6.1	30	S/Sh/Bo
	8[3]	18-Aug	-			no transect laid							4	6.1		R
2	9	18-Aug	1144	5.2	12.9	220	44	0.958	325	0	16	0.74	4	6.1	30	S/M
2	10	18-Aug	1302	2.3	13.6	105	21	0.958	127	0	12	0.60	4	6.1	30	S/Bo
2	31	21-Aug	1128	3.9	12.6	160	32	1.000	547	0	64	1.71	4	4.6	20	M/S
2	32	21-Aug	1317	1.9	10.2	165	33	1.000	127	0	11	0.38	4	4.6	35	M/S
2	33	21-Aug	1429	2.6	14.8	200	40	1.000	2247	0	169	5.62	4	4.6	50	S/Sh/Bo
2	34	21-Aug	1537	6.6	15.3	55	11	1.000	957	0	152	8.70	4	4.6	40	S/Sh/Bo
2	35	21-Aug	1612	4.6	15.5	100	20	1.000	350	0	64	1.75	7	4.6	20	S/Bo
2	38	22-Aug	1021	5.6	13.8	105	21	1.000	444	0	75	2.11	7	4.6	20	S/Sh/G
2	39	22-Aug	1118	5.6	11.8	125	25	1.000	838	0	182	3.35	7	4.6	30	Sh/S/Bo
2	40	22-Aug	1222	3.8	12.9	45	9	1.000	483	0	151	5.37	7	4.6	20	S/Bo
2	41	22-Aug	1248	4.4	14.1	30	6	1.000	283	0	256	4.72	7	4.6	30	S/Bo/C
2	42	22-Aug	1312	5.5	13.3	45	9	1.000	10	0	4	0.11	7	4.6	0	Sh/Bo/C
2	42.1	22-Aug	1430	0.1	5.7	65	13	1.000	133	0	47	1.02	4	6.1	20	S
2	43	22-Aug	1337	6.4	12.6	65	13	1.000	1220	0	219	9.38	7	3.0	75	S/Sh
3	16	19-Aug	1021	7.9	12.7	360	72	0.957	536	0	28	0.74	7	6.1	20	Sh/Bo/G
3	17	19-Aug	1136	0.1	13.8	50	10	0.957	21	0	10	0.21	7	6.1	5	Bo/C/R
3	18	19-Aug	1202	2.8	15.7	100	20	0.957	3	0	3	0.02	4	6.1	0	Bo/Sh
3	22	19-Aug	1633	2.8	14.2	155	31	0.957	299	0	96	0.96	8	6.1	20	Bo/Sh/C

Table 3 (cont'd)

Survey Site	Trans.	Date	Time Start	Depth (m) Min	Depth (m) Max	Transect Length (m)	# of Quadrats	Show Factor	Geoducks Counted Total	Geoducks Counted Min	Geoducks Counted Max	Density (#/m²)	Site Exp.[1]	Water Visibility (m)	Neck Exp. (%)	Substrate[2]
3	23	20-Aug	0920	2.5	12.7	90	18	0.957	118	0	40	0.66	7	4.6	0	Bo/S/Sh
3	24	20-Aug	0959	4.6	14.3	95	19	0.957	757	0	158	3.98	8	4.6	25	S/Bo
3	25	20-Aug	1055	10.0	13.3	200	40	0.957	764	0	59	1.91	8	4.6	15	Sh/S
3	26	20-Aug	1241	12.4	13.4	100	20	0.957	74	0	23	0.37	8	4.6	15	S/Sh
3	27	20-Aug	1323	2.9	14.8	185	37	0.957	2807	0	182	7.59	8	4.6	10	S/M/Bo
3	28	20-Aug	1447	3.2	16.2	275	55	0.957	4776	3	264	8.68	4	6.1	45	S/Sh
3	29	20-Aug	1730	3.8	13.4	195	39	0.957	1155	0	99	2.96	7	4.6	50	S/Sh/R
3	30	21-Aug	0920	6.0	14.4	240	48	1.000	5288	0	337	11.02	8	4.6	20	S/Sh/R
3	35.1	21-Aug	1650	5.3	14.7	155	31	1.000	1415	0	318	4.56	8	4.6	55	Sh/S
3	36	22-Aug	0916	12.4	15.6	140	28	1.000	1447	5	162	5.17	7	4.6	15	Sh/S
3	36.1	22-Aug	1508	5.9	14.1	40	8	1.000	0	0	0	0.00	8	6.1		Bo/C
	37[3]	21-Aug	-			no transect laid							7			R
4	11[3]	18-Aug	-			no transect laid										R
4	12[3]	18-Aug	1638	4.7	13.1	35	7	0.971	0	0	0	0.00	7	6.1		R/Sh
4	12.1[3]	19-Aug	0903			no transect laid										R.Bo
4	13[3]	18-Aug	1558	9.0	13.5	100	20	0.971	30	0	13	0.15	7	6.1	0	Sh
4	14[3]	18-Aug	1423	7.9	12.3	100	20	0.971	0	0	0	0.00	7	7.6		Bo/Sh
4	15[3]	19-Aug	0940	0	12.0	60	12	0.957	0	0	0	0.00	7	6.1		Bo/Sh
4	19[3]	19-Aug	1320	4.7	15.6	90	18	0.957	225	0	74	1.25	8	6.1	20	Bo/C/Sh
4	20[3]	19-Aug	1413	3.9	13.6	285	57	0.957	12	0	3	0.02	8	4.6	5	Sh/Bo/C
4	21[3]	19-Aug	1540	6.8	15.1	100	20	0.957	1	0	1	0.01	8	6.1	0	Sh/Bo/R

[1] 4= Moderate exposure, 7=Ground swell normal, 8=High exposure.

[2] S=sand, Sh=shell, M=mud, Bo=boulder, R=bedrock, C=cobble, G=gravel.

[3] Transects that were excluded from data set for calculating density.

Table 4. Estimates of geoduck density (#/m^2) and biomass (t) (adjusted with show factor) with bootstrapped estimates of 95% confidence interval, by survey site, for the geoduck survey at Griffith Harbour, Aug. 15-23, 1995. A mean weight of 1.242 kg was used to convert density in number of animals to biomass.

Survey Site	Area Surveyed (ha)	Number of Transects	Survey Density (#/m^2)			Survey Biomass (t)		
			Mean	95% C.I.		Mean	95% C.I.	
1	**55.5**	**8**	**1.7**	**1.0**	**2.5**	**1,177**	**487**	**2,060**
2	**35.4**	**13**	**2.8**	**1.5**	**4.4**	**1,242**	**533**	**2,232**
3 all data	58.8	15	4.2	2.0	6.3	3,072	1,170	5,598
filtered[1]	**58.8**	**12**	**2.4**	**1.0**	**4.1**	**1,767**	**572**	**3,451**
4[2]	18.3	7	0.2	0.0	0.6	43	1	144
1-3 all data	149.7	36	2.9	1.9	4.1	5,361	2,670	8,860
filtered[1]	**149.7**	**33**	**2.2**	**1.6**	**3.0**	**4,129**	**2,083**	**6,681**

[1] Excluding transects 28, 30 and 35.1, with exceptionally dense patches of geoducks.
[2] Site 4 was not included in overall density estimate calculations and bootstrapping for confidence intervals.

Table 5. Comparison of mean biomass estimates (t), as determined with various combinations of mean density (# geoducks/m^2) and bed area (ha) estimates, and a mean weight of 1.242 kg from market samples.

	Mean Density (#/m^2)	Area (ha)	Mean Biomass (t)
1. Pre-survey digitized bed area and density estimates.	1.8	182.4	4,104
2.			
3. New digitized bed area; survey density estimate **including** extreme data.	2.9	152.5	5,488
4. New digitized bed area; survey density estimate **excluding** extreme data.	2.2	152.5	4,164
5. Area surveyed (mean transect length x shoreline distance); survey density estimate **including** extreme data.	2.9	149.7	5,361
6. Area surveyed (mean transect length x shoreline distance); survey density estimate **excluding** extreme data.	2.2	149.7	4,129

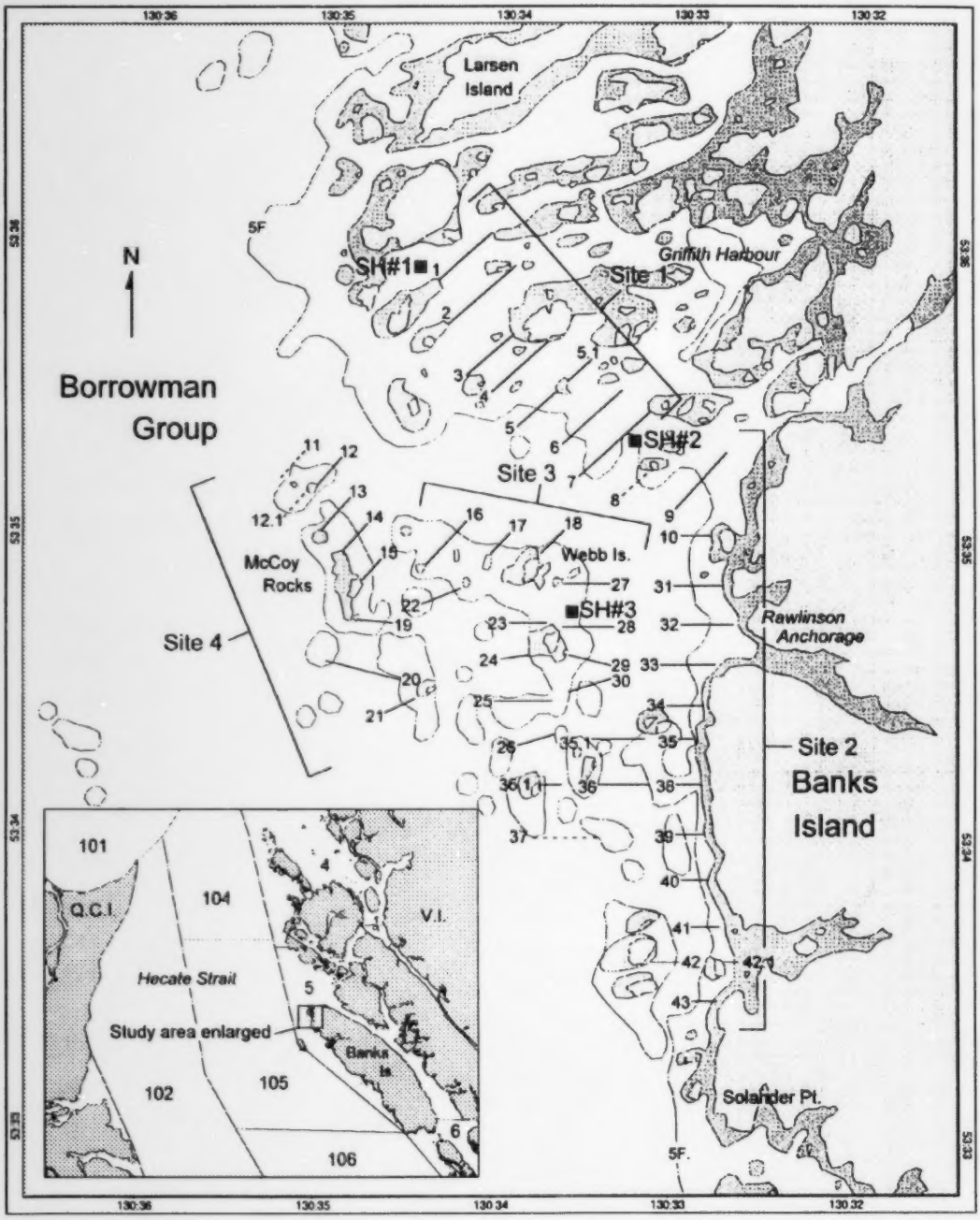

Figure 1. Location of survey sites, transects and show factor sites (SH) for the survey conducted in the Griffith Harbour area in August, 1995. The location of Griffith Harbour on Banks Island, British Columbia is shown in the inset. Transects drawn as dotted lines indicate where the substrate was bedrock and no line was laid.

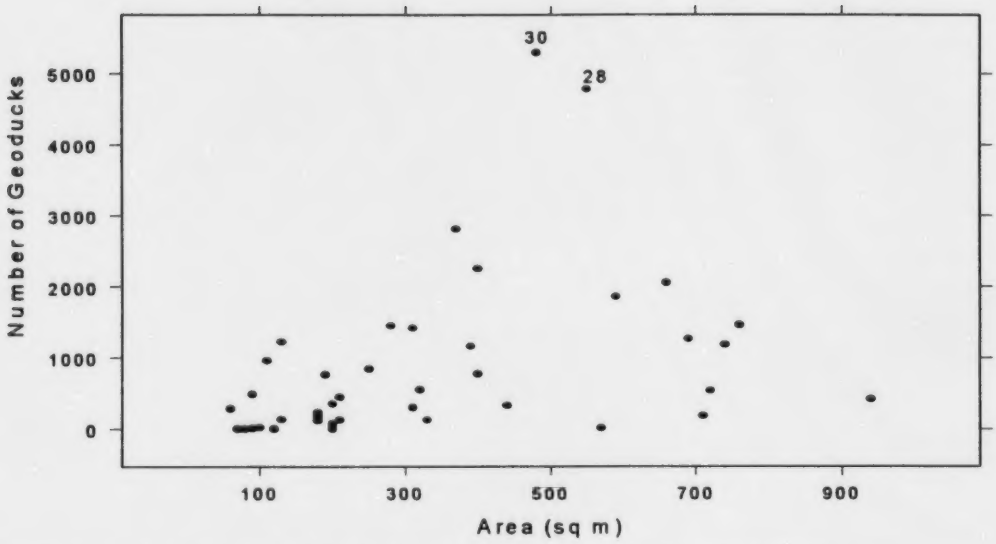

Figure 2. Plot of the number of geoducks versus the transect area (sq m). Two transects with extremely high counts of geoducks are labelled.

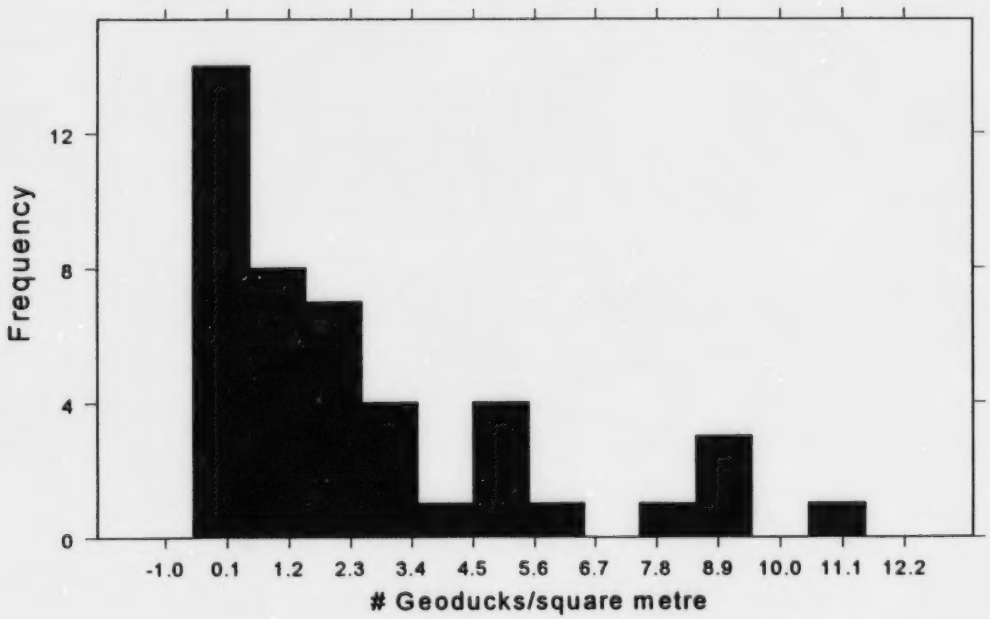

Figure 3. Frequency distribution of transect densities (# geoducks/m^2).

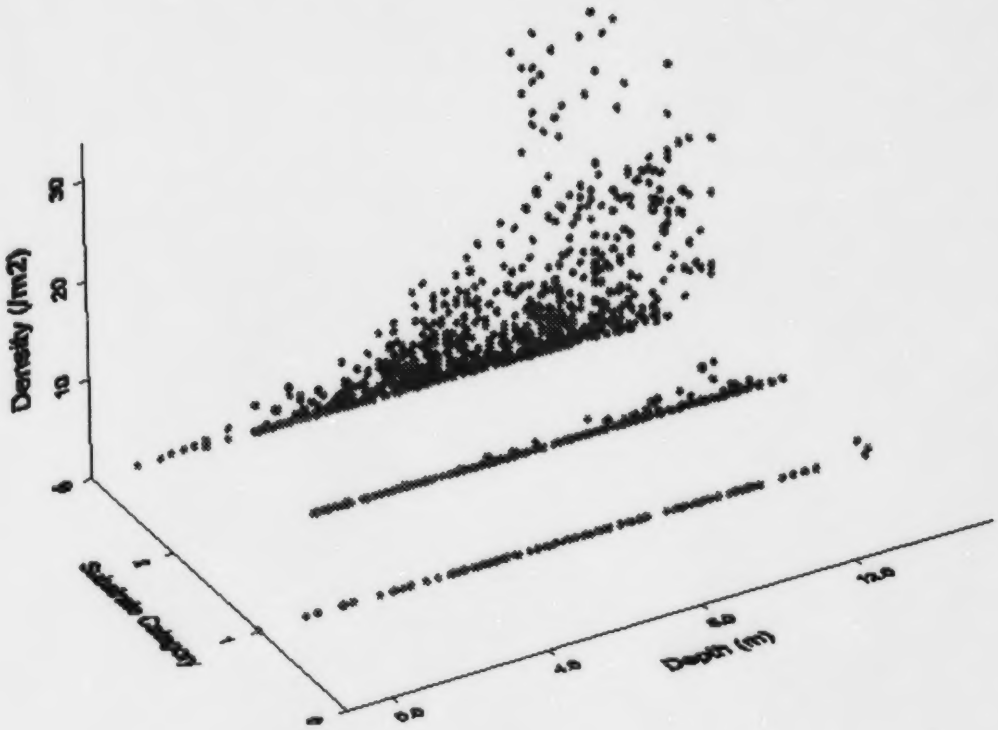

Figure 4. Geoduck density (#/m^2) by depth (m) and substrate category for the Griffith Harbour survey, August 15-23, 1995. Category (1) bedrock, (2) mixed sand and rock and (3) sand/shell. Density data are not adjusted for show factor.

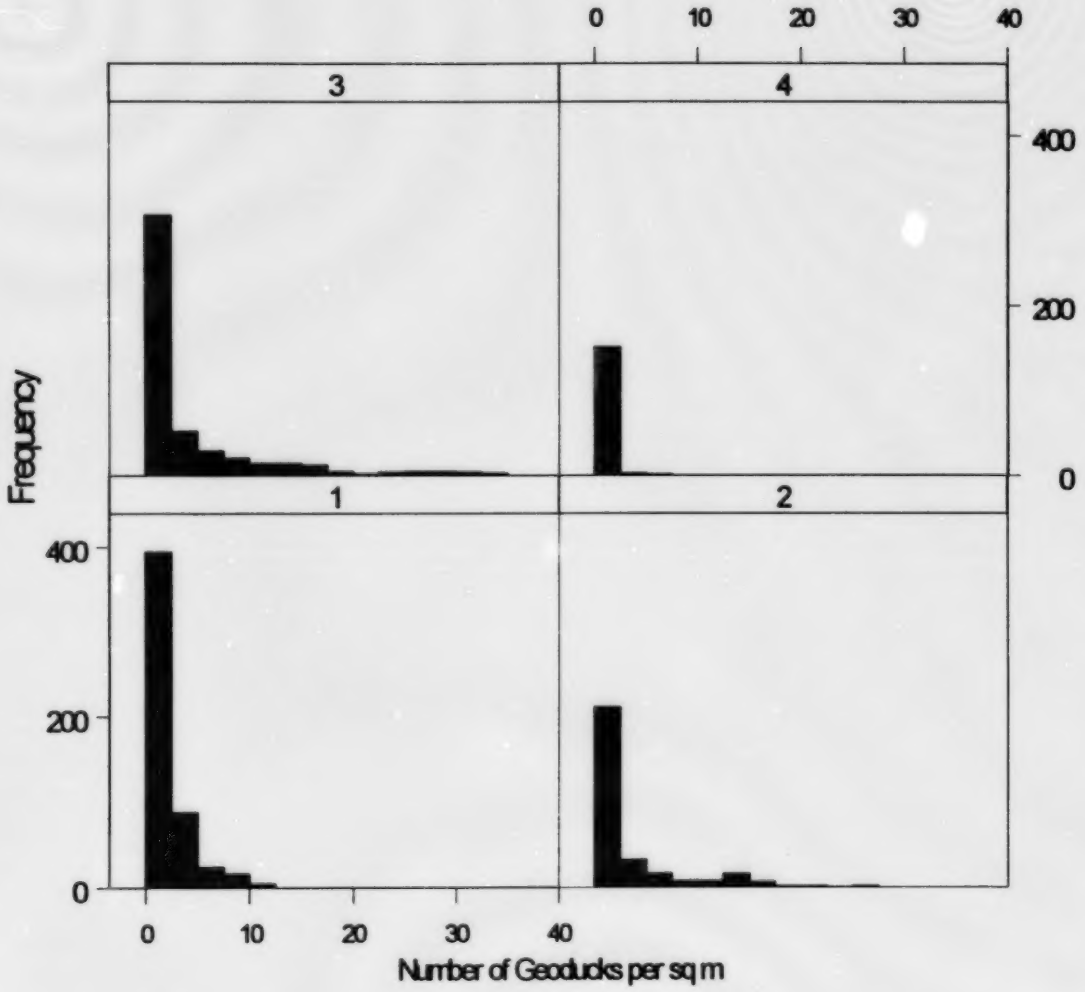

Figure 5. Frequency distribution of the density of geoducks (# geoducks/m^2) per 10^2 quadrat, by survey site.